



Nanolaminate Mirror Development at ATK-COI

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OUTLINE



- ◆ Objectives and Requirements
- ◆ Challenges with Composites in Mirror Design
- ◆ Design Development of Composite / Nanolaminate Hybrid
- ◆ Predicted Performance
- ◆ Prototype Fabrication and Test
 - » Figure
 - » Roughness
 - » Mass
- ◆ Conclusions and Recommendations



Objectives and Requirements



◆ Objectives

- » Lightweight Mirrors for Large Aperture Space Telescopes
- » Replicated Nanolaminate Foil Serves as the Optical Surface
- » ATK-COI to Develop a Composite-Based Backing Structure to Support Nanolaminate Foil.

◆ Considerations

- » Meets Requirements (See Table)
- » Ease of Manufacturing (Rapid, Low \$)
- » Assume no actuation

◆ NRO-Funded Investigation

- » \$100K / 9-month Effort

| Attribute | Value | Units |
|-------------------------|-----------|-------------------|
| Diameter | > 1 | m |
| Areal Density | < 5 | kg/m ² |
| Surface Accuracy (P-V) | 20 | nm |
| Surface Roughness (RMS) | 2 | nm |
| Temperature Range | 250 - 350 | K |



Development Tasks



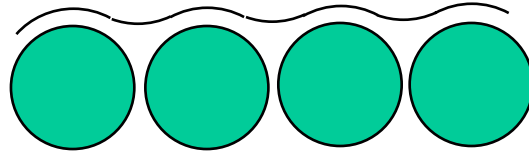
- ◆ **Design**
 - » Mitigate Fiber and Core Element Print-Thru
 - » Mitigate Moisture Deformation
 - » Balanced and Symmetric for Thermal Stability
 - » Meet 5 kg/m² Areal Density Goal – Challenging!
 - » Predict Performance via Simple Laminated Plate Theory
- ◆ **Process Development**
 - » Adhesive Selection
 - » Nanolaminate Bonding Process
- ◆ **Demo Mirror Fabrication**
 - » Two mirrors @ 2.5"
 - » Final Deliverable @ ~10"
- ◆ **Mirror Evaluation**
 - » Figure – simple Fizeau fringes
 - » Roughness – NASA/MSFC



Implementation Challenges with Composites



- ◆ **1) Micro-Level: Diffuse Surface Effects**
 - » **Fiber Print-Thru Limits Operational Wavelength**
 - » **“Typical” Laminate Roughness ~ 100 nm RMS**



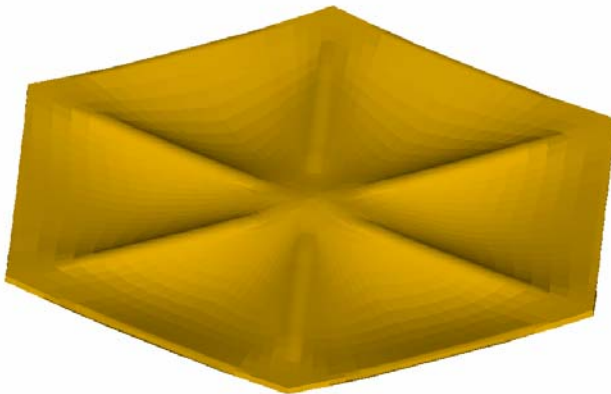
- » **COI Developed Solution(s)**
 - **Additional Adhesive Layer at Surface (Replicated)**
 - **Application of a Polishable Coating**
 - **Application of a Metallic Coating for Diamond Turning**
- » **Nanolaminate Mirror Considerations**
 - **Nanolaminate Foil Can Potentially Mask Underlying Fibers**



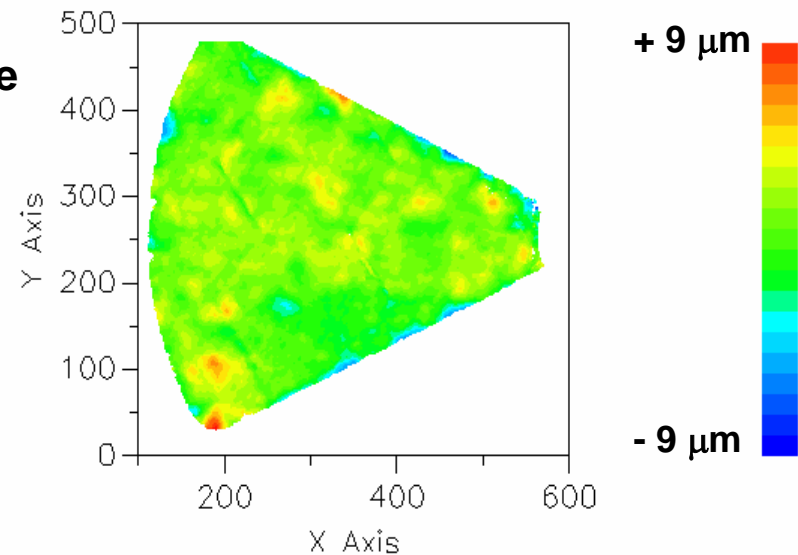
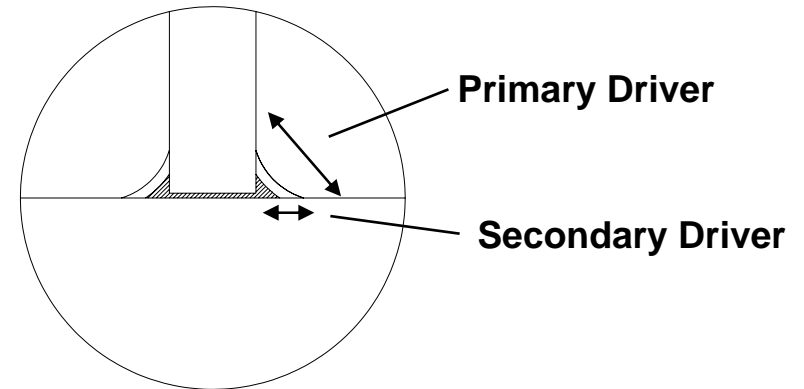
Implementation Challenges with Composites



- ♦ **2) Macro Level:
Bonded Construction Effects**
 - » Rib Print-Thru affects Mirror Figure
 - » COI Heritage Solution(s)
 - › Null Figuring (Ion)
 - › Careful Adhesive Control
 - › Solid Core (Foam) Design Alternatives
 - » Nanolaminate Considerations
 - › Difficult to Meet Figure w/ Discrete Rib Core



**12" NMSD Hybrid Demo Mirror:
Deformation from Bonding @ RT**



**FIRST Mirror Segment:
Quilting @ 70K**

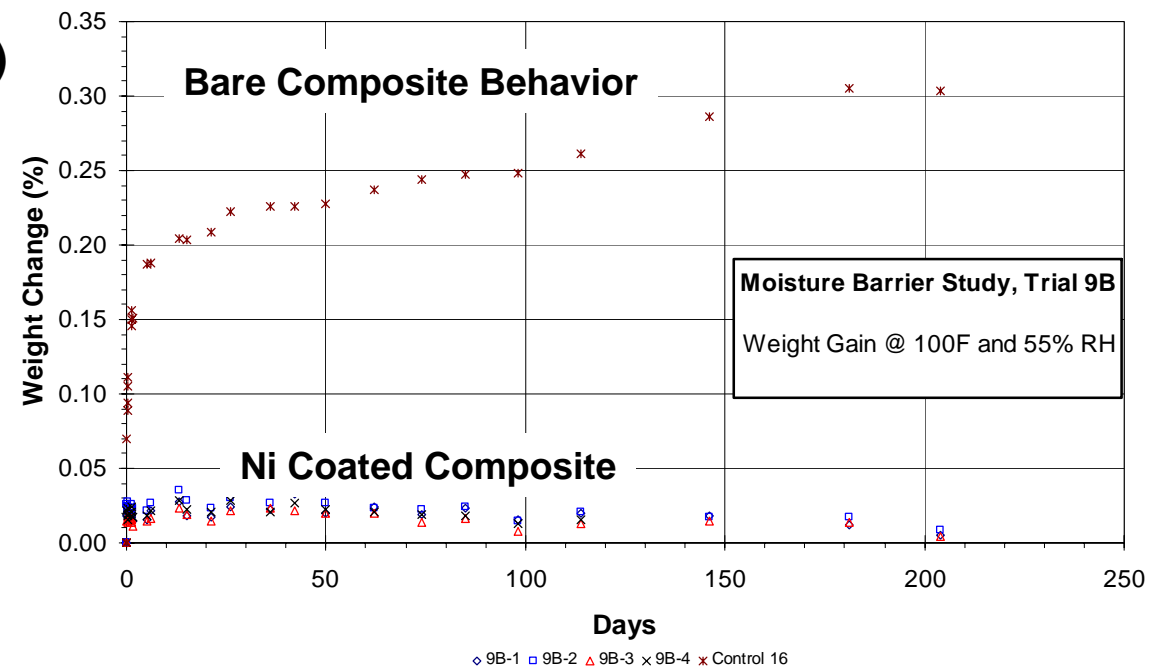


Implementation Challenges with Composites



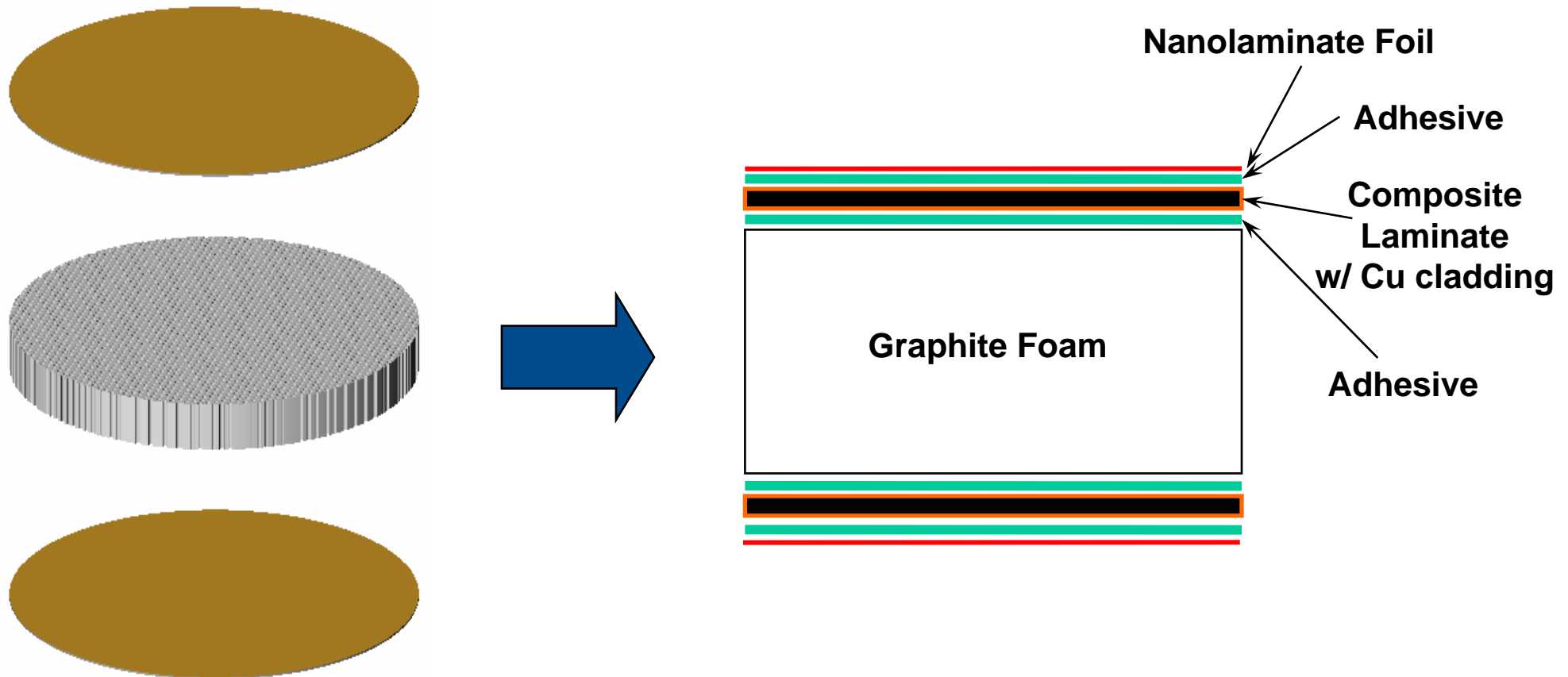
◆ 3) Moisture Instability

- » Moisture Expansion Can Be Dominant Error Source – Greater Than Thermal Expansion Effects (Typical CME ~ 100 ppm/%M)
- » COI Heritage Solution(s)
 - Lower Moisture Uptake Resins
 - Plate and/or Clad Composites
- » Nanolaminate Consideration(s)
 - Recommend a Coating for CFRC





Composite / Nanolaminate Hybrid Mirror Design





Composite / Nanolaminate Hybrid Design Characteristics



♦ SYMMETRIC / BALANCED STRUCTURE

- » Mitigates unstabilizing effect of high CTE nanolaminate
- » Ensures curvature change (only) in a powered optic over temperature range
- » High CTE adhesives, and inherently anisotropic CFRC make even this approach challenging to meet $\lambda/20$ Requirement
- » Imperfections in balance/symmetry will lead to higher order errors

♦ CONTINUOUS CORE

- » Discrete Rib Approach for Core Not Viewed as Capable of Meeting Figure/Stability Requirement
- » Primary function is to separate facesheets to achieve stiffness

♦ MASS CHALLENGE ACHIEVABLE

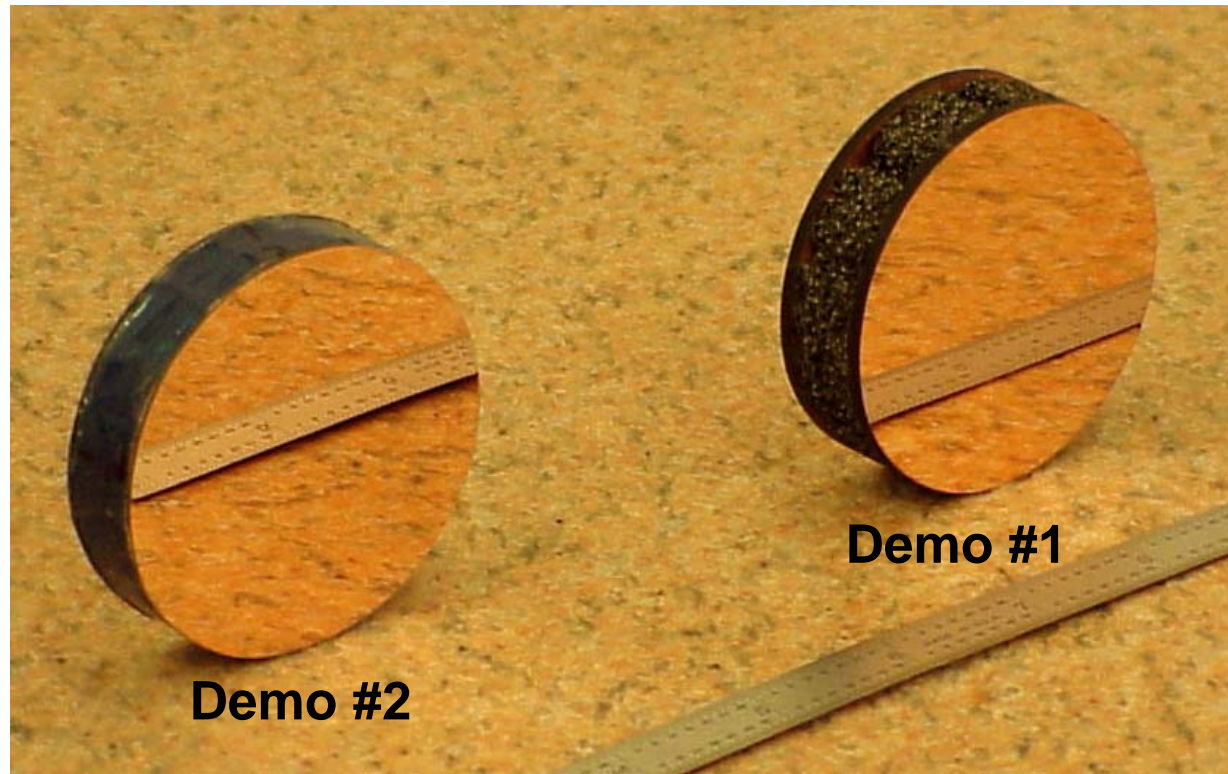
- » 0.020" Thick CFRC Laminate = 1 kg/m²



Prototype Fabrication and Test



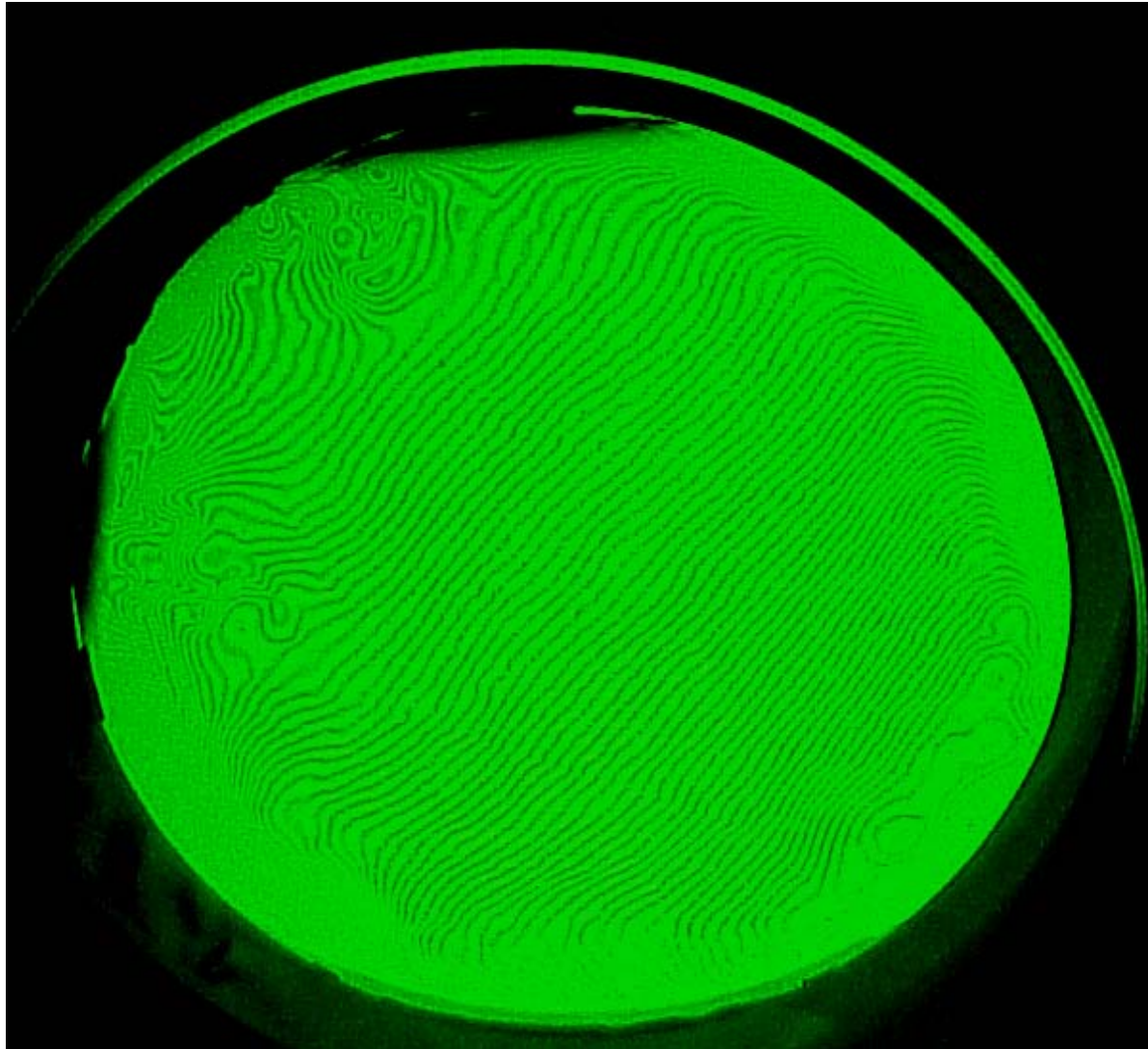
3 Mirrors Fabricated and Tested



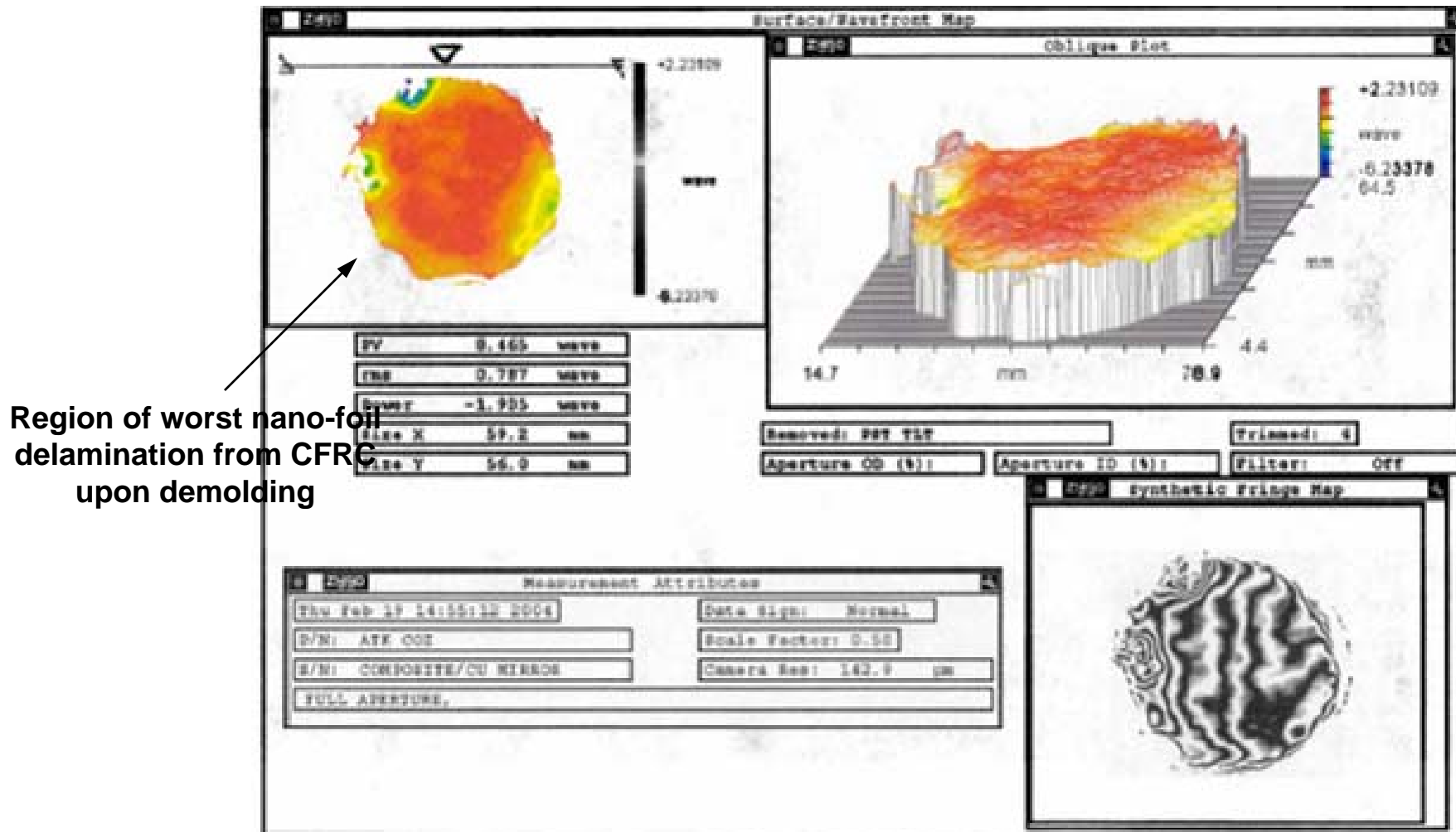
- ◆ **Two small (2.5") manufacturing pathfinder / proof-of-concept mirrors**
 - » Figure evaluated with both optical flat and interferometer
 - » Roughness measured with WYKO
- ◆ **9" FLAT as Final Deliverable**
 - » Central aperture (only) evaluated to-date
 - » Complete figure evaluation in-work

Fringe Evaluation

Optical Axis Facing Up

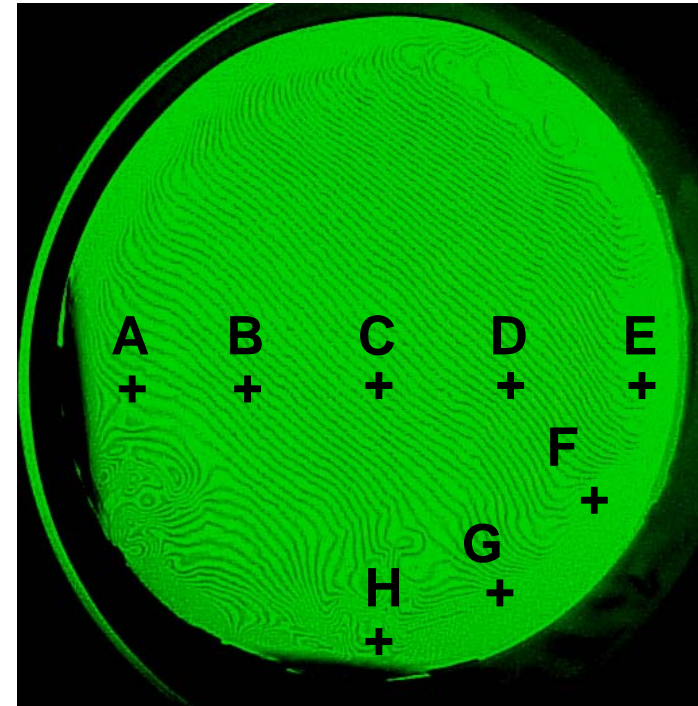


- ♦ Edge errors predominately due to damage (delamination of nanolaminate foil from substrate) sustained during de-molding operation



- ♦ Mirror supported vertically (resting at two points on edge, and one point on backside) during test

- ♦ WYKO Interferometer
 - » 1 mm x 1 mm sample area
 - » 256 x 256 pixels
 - » ~5Å resolution, with ~1Å repeatability
- ♦ ~ 40 angstrom roughness across central aperture (vs. ~ 5 Å RMS mandrel roughness)
- ♦ Results indicate minor print-thru of fibers and/or fiber bundles to surface
- ♦ Higher edge readings associated with delamination of nano-foil from substrate (caused during de-molding)
- ♦ Similar readings made on all three demo substrates

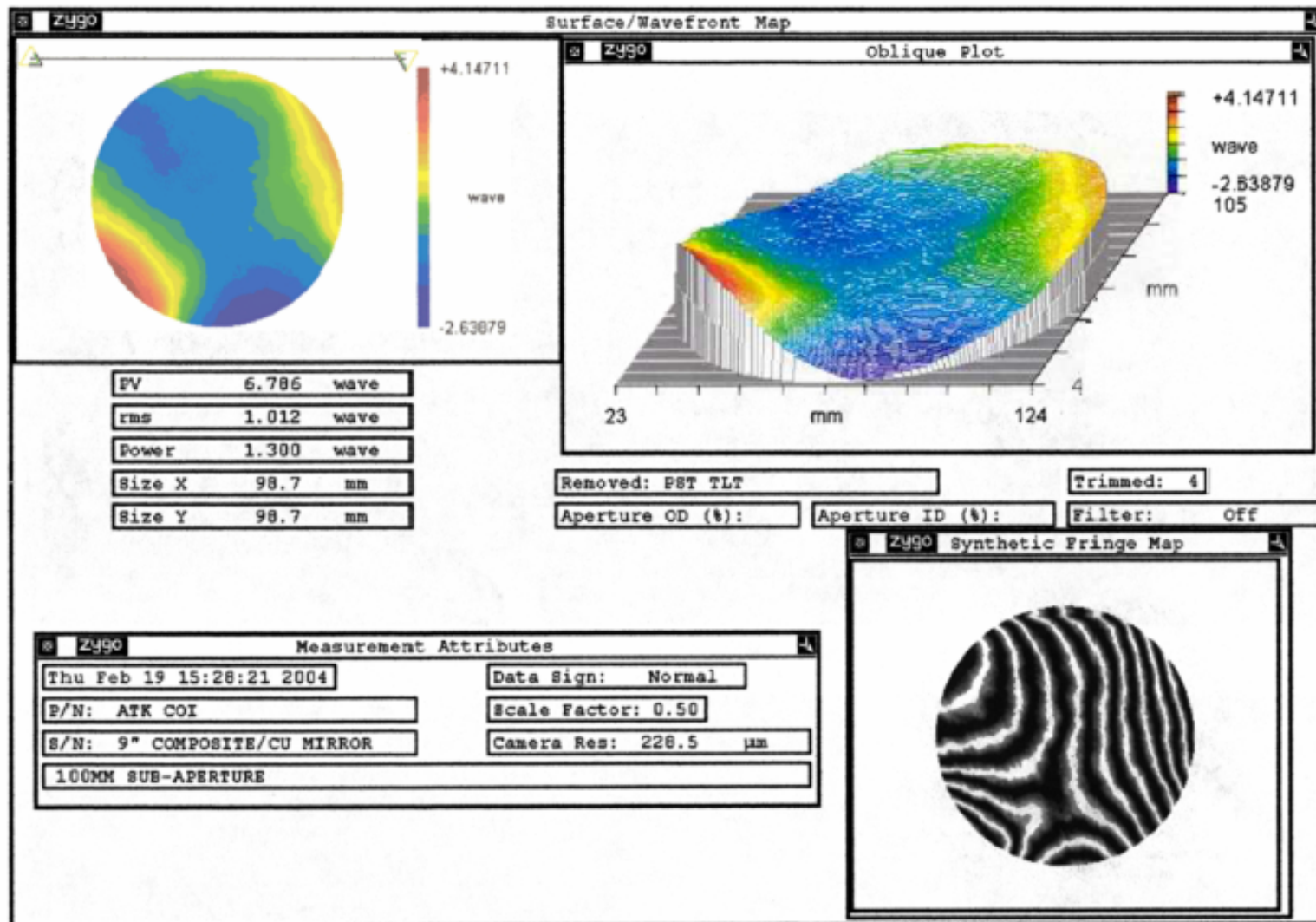


| | | | | |
|---|----|--|---|----|
| A | 44 | | E | 39 |
| B | 65 | | F | 54 |
| C | 43 | | G | 94 |
| D | 44 | | H | 76 |

All values in Å RMS



Final Deliverable (9" Flat)



- ♦ ZYGO interferometer used to capture the central ~4-inches of Mirror #3
- ♦ Mirror supported vertically (resting at two points on edge, and one point on backside)



Summary of Results



♦ 3 Mirrors Fabricated and Evaluated

| | Mirror #1 | Mirror #2 | Mirror #3 |
|----------------------------|--|---------------------------------|-------------------|
| Aperture | 2.5" | 2.5" | 8.8" |
| Nanolaminate Configuration | One Side | Two Sides | Two Sides |
| Estimated Surface Figure | 13 waves (Power) | 0.8 wave | ~1 – 5 waves |
| Surface Roughness | 35 – 85 Å (includes edge values) | 40 – 100 Å | 45 – 90 Å |
| Comments | Figure Error due to Disbond of <i>faceskin</i> from core | Geometries and Approach refined | Final Deliverable |



Conclusions & Recommendations



◆ Demonstrated Feasibility of Meeting All Objectives, Except Figure

| Attribute | Value | Units | Compliance Demonstrated |
|-------------------------|-----------|-------------------|---|
| Diameter | > 1 | m | Use of Scalable Materials & Processes |
| Areal Density | < 5 | kg/m ² | Demo #2 and Final 9" Mirror |
| Surface Accuracy (P-V) | 20 | nm | Non Compliant; HOWEVER... NRO interests now include scenario for mirror actuation |
| Surface Roughness (RMS) | 2 | nm | Measurements to date suggest print-thru of fiber/bundle morphology to optical surface |
| Temperature Range | 250 - 350 | K | Balanced Design Ensures max. Stability with Temperature |

◆ Following Efforts Recommended as Part of Continued Development:

- » Mask/coat fiber print-thru
- » Assembly Process Optimization
- » Improve laminate design/accuracy
- » Improve Metrology / Feedback
- » Interface Properties